INEEL/CON-98-00879
PREPRINT

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February 28, 1999 – March 4, 1999

Waste Management '99

EVALUATING IN SITU TREATMENT TECHNOLOGIES FOR BURIED MIXED WASTE REMEDIATION AT THE INEEL[1]

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ABSTRACT

Mixed radioactive and hazardous wastes were buried at the Department of Energy's Idaho National Engineering and Environmental Laboratory (INEEL) Subsurface Disposal Area from 1952 to 1969. To begin the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) remediation process for the Subsurface Disposal Area, the Environmental Protection Agency (EPA) added the INEEL to its National Priorities List in 1989. DOE's Office of Environmental Restoration is planning several CERCLA treatability studies of remedial technologies that will be evaluated for potential remediation of the buried waste in the Subsurface Disposal Area. This paper discusses the in situ treatability studies that will be performed, including in situ vitrification, in situ grouting, and in situ thermal desorption.

The in situ treatability studies will be conducted on simulated and actual buried wastes at the INEEL in 1999 and 2000. Results from the treatability studies will provide substantial information on the feasibility, implementability, and cost of applying these technologies to the INEEL Subsurface Disposal Area. In addition, much of the treatability study data will be applicable to buried waste site remediation efforts across the DOE complex.

INTRODUCTION

From 1952 to 1969, mixed hazardous and radioactive wastes from various sites within the Department of Energy (DOE) complex were buried at the Idaho National Engineering and Environmental Laboratory (INEEL). A primary location for burial of these wastes is the Subsurface Disposal Area, located at the INEEL Radioactive Waste Management Complex. The Subsurface Disposal Area contains numbered pits, trenches, soil vault rows, and interim storage pads over an area of 38.9 ha (96 acres). In 1989, the Environmental Protection Agency (EPA) added the INEEL to its National Priorities List, under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

A feasibility study is being performed to support the Subsurface Disposal Area Record of Decision (ROD). The feasibility study identifies remedial action objectives; identifies potential treatment and containment technologies that will satisfy these objectives; screens the technologies based on their effectiveness, implementability, and cost; and assembles technologies and their associated containment or disposal requirements into alternatives. To perform the feasibility study, there must be sufficient information on remedial technologies to evaluate them. This data is being obtained from several sources, including existing data and ongoing work at the INEEL and other DOE laboratories, a planned limited retrieval of the Subsurface Disposal Area Pit 9, ex situ treatability studies, and in situ treatability studies. The purpose of treatability studies is to fill data gaps for applicable technologies, which will aid in selecting and implementing a remedy. The results of the treatability study are expected to reduce the uncertainties associated with selecting the remedy and to develop a sounder basis for the ROD.

The original date for completion of this ROD was 1999. The ROD completion has been extended to 2003 to ensure that adequate remedial technology data is considered. The schedule extension provides an opportunity to evaluate in situ treatments that may offer substantial benefits in remediating a major portion of the buried waste sites within the Subsurface Disposal Area. Hence, DOE's Office of Environmental Restoration is planning several treatability studies to support the feasibility study and ROD. The treatability studies will be conducted on simulated and actual buried wastes at the INEEL in 1999 and 2000.

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1 Work supported by the U.S. Department of Energy, Assistant Secretary for Environmental Management, under DOE Idaho Operations Office Contract DE-AC07-94ID13223.

The DOE, in collaboration with EPA and the Idaho Department of Health and Welfare (IDHW), identified several remedial technology data gaps that must be addressed to support the comprehensive feasibility study for the Subsurface Disposal Area (1). In 1997, several value engineering workshops and a preliminary system analysis were conducted to assess both in situ and ex situ remedial alternatives (2). These led to a series of scoping meetings in late 1997, with DOE, EPA, and IDHW participation, to define strategies to address feasibility study data gaps. These meetings culminated in January 1998 with a DOE-sponsored industry forum to identify other potential remedial technologies.

Candidate technologies for treatability studies were reviewed using the EPA guidance for selection of treatability studies (3). This guidance provided a method to evaluate which treatability studies should be performed to support the feasibility study and the ROD. The evaluation was based on the significance of feasibility study data gaps associated with each technology and whether bench-, pilot-, or field-scale testing would collect the necessary treatability study data. Other factors considered by DOE, EPA, and IDHW to determine which treatability studies will be implemented were budget and schedule constraints, technology availability, level of technology development and demonstration, and potential applicability at the Subsurface Disposal Area. Four technology areas were determined to warrant treatability studies. However, should other technologies with potential application at the Subsurface Disposal Area mature sufficiently before the ROD is initiated, additional treatability studies may be defined through consensus by the DOE, EPA, and IDHW remedial project managers. The treatability studies currently planned include the following:

- In situ vitrification (ISV)
- In situ grouting (ISG) for long-term disposal and for confinement during retrieval
- In situ thermal desorption (ISTD)
- Ex situ soil treatments (electrochemical oxidation and high-gradient magnetic separation).

The purpose of this paper is to describe the three in situ remediation technology treatability studies. A number of uncertainties with the quality and long-term durability of the resultant waste form(s), with in situ processing itself (e.g., emissions, process upsets), and with the ability to verify waste types, process completion, and resultant waste form quality will be investigated. In addition, in situ treatment technologies have uncertainties associated with contaminant fate that are more complex than those of most ex situ treatment technologies. To address these uncertainties, the evaluation of in situ remediation technologies requires large-scale treatability study testing.

Presented below is a summary of each in situ treatment technology and what types of testing and evaluations are planned.

IN SITU VITRIFICATION

Technology Description

The ISV process, as illustrated in Figure 1, melts soil in place using electricity applied between pairs of graphite electrodes. The electrodes are inserted 1–2 ft in the ground, in a square or rectangular configuration up to 26 ft apart. To initiate startup, a highly conductive starter path of graphite and glass-forming compounds is placed between the electrodes. An electric potential is then applied to the electrodes and starter path, causing the soil surrounding the starter path to melt. Once the soil is molten, it too becomes electrically conductive. Continued application of electricity results in joule heating within the molten soil between the electrodes. After the melt is fully established, the melt zone grows steadily downward and outward through the contaminated media, as the graphite electrodes are gravity-fed downward into the melt.

During ISV processing, nonvolatile metals and radionuclides are chemically incorporated into the vitrified product. Volatile metals (such as mercury) are vaporized and removed by the off-gas treatment system. Organic contaminants are typically destroyed by pyrolysis in the ground, and the pyrolysis products travel to the ground surface where they are oxidized in an off-gas hood. Vapors from the off-gas hood are then processed by the off-gas treatment system before being discharged to the atmosphere. The highly reducing nature of the ISV melt may result in some metals (e.g., iron) being reduced and settling to the bottom of the melt as a separate phase. Vitrification work performed on high-level waste has demonstrated that actinides of concern in the Subsurface Disposal Area, (e.g., uranium and plutonium) will not be reduced because of their high oxidation potentials and are therefore expected to remain in the glass phase (4). Incorporation of actinides in the glass phase is supported by recent tests on uranium- and plutonium-contaminated soils (5).

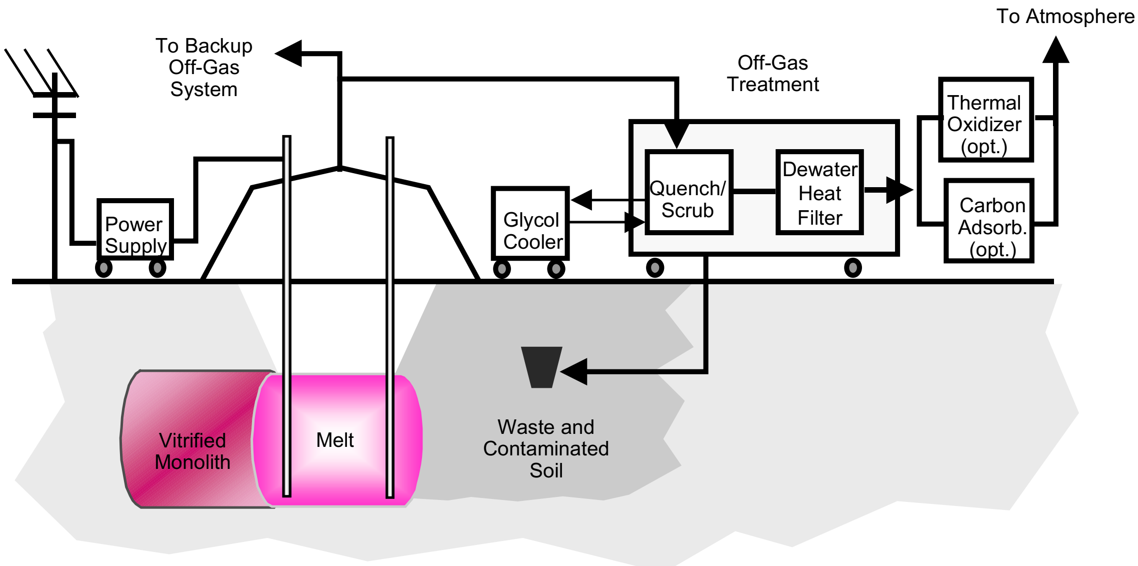

Figure 1. Schematic of ISV (courtesy of Geosafe Corporation).

Upon cooling, the ISV process produces a vitreous rock-like material totally free of organic material, with a physical strength approximately ten times greater than concrete. The vitrified product is extremely leach resistant, typically passing even the most stringent leach tests. Life expectancy of the vitrified product is expected to be similar to naturally occurring obsidian, which has a life expectancy measured in millions of years when exposed to the natural environment (4).

The ISV off-gas system consists of an off-gas collection hood, a quencher, a scrubber, a demister, a heater, a particulate filter, a blower, and an optional activated-carbon adsorber and its associated thermal oxidation units (see Figure 1). The dome-shaped off-gas hood completely covers the area to be treated and collects emissions generated at the treatment zone. A low vacuum in the off-gas hood pulls gases to the off-gas treatment system. The off-gas is first processed by the quencher to lower its temperature and by the scrubber to remove acid gases and large particulate. It is then dewatered and reheated to prevent wetting of the particulate filters. Finally, it is filtered to remove the particulate and then polished to remove trace organics (using either an activated carbon adsorber or a thermal oxidation unit) before being released to the environment.

ISV was first developed in 1983 by Battelle, at Pacific Northwest National Laboratory, for remediating radioactive-contaminated soils. Since that time, its application has been expanded to include both mixed- (hazardous and radioactive) and hazardous-contaminated soils and debris wastes, as well as underground tanks. The first large-scale applications of ISV operated by Battelle on radioactive waste sites were performed on two plutonium and americium contaminated soil cribs at Hanford in 1986 and 1990 (6). In 1990, the INEEL in collaboration with Pacific Northwest National Laboratory conducted the first field-scale melts on simulated buried wastes. These tests used simulated waste forms based on records of waste disposal at INEEL's Subsurface Disposal Area. Gravity electrode feeding was successfully implemented during these tests demonstrating ISV processing of high metal content wastes (7).

The most recent DOE large-scale radioactive demonstration was conducted by Pacific Northwest National Laboratory in 1996 on Pit 1 at the Oak Ridge National Laboratory. Pit 1 was used as a seepage basin for the disposal of radioactive liquids containing cesium and strontium. In this demonstration, ISV proceeded smoothly to a melt depth of approximately 4.3 m (14 ft) when pressurized vapors beneath the melt caused an expulsion of molten soil from the treatment zone. In the resulting incident investigation, the presence of water in a relatively impermeable clay formation was found to be the primary factor for the melt expulsion. However, no detectable levels of airborne contamination were released and cleanup actions were limited to recovery of the glass that had been ejected onto the ground surface (8).

In 1986, Battelle created Geosafe Corporation for commercializing ISV. ISV has been applied commercially to the remediation of waste at the Parsons Site in Grand Ledge, Michigan, a staged (i.e., prepared) site containing soils contaminated with pesticides and metal; the General Electric Spokane Site in Spokane, Washington, a staged site filled with drums containing moist, PCB-contaminated soil; and the Wasatch Chemical Site in Salt Lake City, Utah, an evaporation pond filled with organic-contaminated soil and debris. In addition, ISV is being applied to the Taranaki pits in Maralinga, Australia, which contain mixed transuranic radioactive soils and debris, and to industrial waste in Japan, using a staged, continual batch version of ISV. Of these sites, the General Electric Spokane Site, the Wasatch Chemical Site, and the Maralinga site are most pertinent to the evaluation of ISV application at the Subsurface Disposal Area because of similarities in the waste characteristics. The General Electric Spokane Site contained sealed drums filled with vaporizable waste (i.e., water and PCBs). Because of concerns about the potential of the sealed drums to cause a melt expulsion, Geosafe applied dynamic disruption with a vibratory rod to disrupt all of the sealed containers in the staged site before successfully processing the waste.

These technology advancements have caused INEEL to consider ISV a promising in situ remediation alternative for remediation of transuranic and low-level waste buried at the Subsurface Disposal Area. The potential advantage of ISV, applied to the buried Subsurface Disposal Area waste, is the substantial reduction in both costs and risks associated with ISV treatment compared to retrieval and ex situ treatment. In addition, ISV should destroy or remove the primary contaminants of concern (i.e., volatile organics) from the buried waste site, and will produce a final waste form that encapsulates all nonvolatile contaminants in a durable glass and crystalline matrix.

Treatability Study Objectives and Strategy

In applying ISV to buried transuranic contaminated waste sites, a number of implementation issues need to be evaluated. Primary implementation issues include melt expulsion potential, contaminant fate, the migratory potential of volatile organics, criticality safety, and verification of the ISV treatment. Based on these concerns, a series of white papers were prepared, discussing the issues and evaluating the existing ISV technology performance data, to determine what “data gaps” need to be evaluated as part of the ISV treatability study. These data gaps were then used to define the objectives of the proposed ISV treatability study. A summary of these data gaps/test objectives is presented in Table 1.

The philosophy of the ISV treatability study is to manage the evaluation of the technology through a graded risk-based approach. Based on research and operating experience, several issues associated with the effectiveness and implementability of the technology in the buried waste environment will be assessed thoroughly. Some of these issues may be “show-stoppers” if they are not adequately resolved. Hence, several decision points are placed in the treatability study to ensure that these key issues will be addressed satisfactorily before committing resources to more extensive testing phases.

The strategy will take advantage of performance data from previous ISV testing and applications and surveillance of ongoing ISV activity, including the work at the Maralinga site, Oak Ridge National Laboratory, and the INEEL. The treatability study is structured to focus on critical data gaps specific to the Subsurface Disposal Area application. Four phases for the ISV treatability study have been defined:

- Phase 1, preliminary evaluation of key uncertainties
- Phase 2, development of test documentation for large-scale testing of simulated and actual waste
- Phase 3, implementation of a large-scale test on simulated waste forms
- Phase 4, implementation of a large-scale test on an actual portion of the Subsurface Disposal Area.

Table 1. ISV Test Objectives and Testing Strategy.

Test Objectives	Strategy			
	Simulated Wastes	Actual Wastes	Bench-Scale	Field-Scale
Evaluate degree of actinide homogeneity in ISV melt	X	X		X
Assess vitrified waste form leachability and durability		X		X
Determine fate and transport of volatile organic contaminants (carbon tetrachloride, TCE, etc.)	X	X	X	X
Evaluate fate of lead		X		X
Evaluate the potential for underground fires	X			X
Determine the feasibility of nitrate salt processing	X		X	X
Evaluate the volume, type, and disposition of secondary wastes		X		X
Evaluate the potential for melt expulsion	X		X	
Evaluate effectiveness of site preconditioning for disruption of sealed containers	X			X
Verify that the intended waste was treated	X	X		X
Assess contamination control needs for site preconditioning and ISV processing	X			X
Evaluate INEEL administrative feasibility for ISV implementation	X	X		X
Determine the time, equipment, and labor requirements for mobilization, demobilization, and operations		X		X

Phase 1—Preliminary Evaluation of Uncertainties. Phase 1 evaluates ISV processing uncertainties at the Subsurface Disposal Area. The critical issues must be sufficiently evaluated to define additional data needs and to determine whether these issues would preclude the use of ISV at the Subsurface Disposal Area, which, therefore, would modify or terminate later treatability study phases.

The primary data gap needing to be evaluated is the potential of melt expulsion during ISV processing. Although recent data suggests that contamination spread resulting from such a melt expulsion is negligible, melt expulsion will affect ISV worker safety and implementability. In addition, the number of sealed 55-gallon drums of vaporizable material in the Subsurface Disposal Area waste is high enough that melt expulsions during ISV processing is possible. Recent Geosafe evidence suggests that melt expulsion potential can be mitigated simply by punching holes in these containers and collapsing any large voids in the waste before beginning conventional-ISV processing. However, such dynamic disruption has not yet been demonstrated in densely packed buried wastes that exist in the Subsurface Disposal Area. For this reason, the proposed treatability study will evaluate the effectiveness of dynamic disruption in preventing ISV melt expulsion.

A second data gap that requires further evaluation is the potential of volatile organic contaminants to migrate away from the advancing ISV melt front into the uncontaminated surrounding soils. Previous ISV tests have concluded that semi-volatile contaminants are primarily destroyed by the ISV process, with the residual undestroyed contamination being volatilized and collected or destroyed in the ISV off-gas system. However, there are concerns that more volatile contaminants will not be destroyed and volatilized by the ISV process, but will be transported into the surrounding soils, ahead of the advancing ISV melt front. Although contaminant migration is not critical in terms of ISV acceptance, it needs to be quantified so that post-ISV cleanup technologies can be defined as necessary.

Phase 2—Test Documentation. Conducting full-scale ISV testing at the INEEL will require significant documentation to adequately address safety, environmental, and operating requirements. A treatability study work plan will be prepared to define the specific data quality objectives and experimental test design necessary to address the data uncertainties as defined in Phase 1. A detailed test plan and sampling and analysis plan also will be prepared for all testing activity. In situ vitrification testing in the Subsurface Disposal Area will require safety and environmental assessment documentation.

Phase 3—Simulated Field-Scale Test. This test will evaluate the effect of dynamic disruption in eliminating melt expulsion concerns during ISV processing. As previously stated, the dynamic disruption evaluation will be performed by a combination of archeological excavation (on half of the simulated test pit), and actual ISV processing response (on the other half of the dynamically disrupted pit). The simulated test pit will be constructed to a depth of 21 ft, consisting of 7 ft of soil overburden, an 11ft buried waste seam, and 3 ft of soil underburden, on top of the basalt sublayer. As with the radioactive field-scale test, the ISV melt will continue 1 ft into the basalt sublayer, for a total melt depth of 22 ft.

Included in the radioactive and simulated field-scale tests is an evaluation of real-time monitoring devices that can monitor the ongoing in situ process in a noninvasive or minimally-invasive manner. The use of these monitoring devices will allow for real-time monitoring of both contaminant migration into the surrounding soil (if present) and the lateral boundaries of the resultant melt.

Bench-scale tests will help define the "worst-case" orientation for placing a sealed gas cylinder into the simulated field-scale test. Proposed orientations include horizontal, vertical right side up, and vertical upside down. The magnitudes of the resulting melt expulsion (if any) will help to define the "worst-case" orientation that should be used in the simulated field-scale test. Another bench-scale test will involve ISV processing of a waste sludge surrogate containing carbon tetrachloride, trichloroethylene (TCE) and tetrachloroethylene (PCE). The amount of contaminant migration into the surrounding soil experienced by these contaminants during ISV processing will then be evaluated.

Phase 4-Large-Scale Actual Waste Test. The first activity will be preparing and preconditioning the selected test site in the Subsurface Disposal Area. Included in site preparation is the placement of thermocouples in any uncontaminated soil sites at various distances away from the ISV melt area. The placement of these thermocouples will provide reference points for (1) pretest sampling of the surrounding soils to quantify any contamination in the surrounding soils and (2) posttest sampling of the surrounding soils to quantify the volatile organic contaminant migration potential for post-ISV. The preconditioning activity will cover the entire waste zone that will be melted by ISV. Contamination control issues will be assessed during preconditioning operations.

ISV processing will proceed in the preconditioned area. The process will be performed using a large-scale electrical power transformer, electrodes, and an off-gas hood and off-gas system. The process will use four graphite electrodes arranged in a three-phase, Scott-Tee electrical connection, with gravity-electrode feeding and electrode-retraction potential. ISV will continue until the melt incorporates the upper part of the underlying basalt layer. During the processing, temperature and pressure measurements will be taken inside the ISV off-gas hood at a rate sufficient to record off-gas rates. Isokinetic sampling will be performed at various positions throughout the ISV off-gas system, including the stack entrance, to quantify the transport of particular contaminants. Measurements necessary for estimating operating costs will be taken during ISV processing.

Information on the volume of secondary waste material (e.g., condensates and HEPA filters) created from the test also will be collected. In addition, samples of each secondary waste material will be collected and analyzed to define ultimate disposition. Geosafe recycles much of the secondary waste in subsequent melts, which limits the quantity that must be otherwise treated and disposed of. The results from this activity will provide a good estimate of the volumes, types, and ultimate disposition of secondary waste generated during ISV processing.

Geophysical techniques (seismic measurements, ground-penetrating radar, and electromagnetic induction) will be used to verify that the intended waste treatment zone was fully vitrified. The test site will be allowed to cool naturally into a hardened monolith (which may take up to 1 year). During cooling, information on the surrounding soil isotherms will be obtained until the positions of the isotherms into which specific volatile organic contaminants may have migrated are ascertained. In addition, samples will be taken in the soil surrounding the melt to quantify the amount of volatile organic contaminant migration that may have occurred during ISV processing. The location of the samples will be defined from the thermocouple data in the surrounding soil.

After cooling, core samples of the vitrified medium will be collected in several locations. Included in the core sample will be a portion of the metal layer at the bottom of the melt. Samples of the glassy and metal phases of the cores then will undergo 1) testing for total cation composition by ion-coupled plasma/mass spectroscopy, 2) toxicity characteristic leaching procedure analysis, 3) product consistency test analysis, and 4) physical characterization. Analyses from these tests will be used to provide information on the contaminant distribution in the glassy phase and product durability. The data from the large-scale hot test will be analyzed and summarized in a final report of conventional ISV application to buried waste sites within the Subsurface Disposal Area. The final report will provide sufficient ISV performance and operational data to support the comprehensive feasibility study for Subsurface Disposal Area.

IN SITU GROUTING

Technology Description

Two types of in situ grouting tests will be performed: grouting for long-term disposal and grouting to provide confinement of contaminants during retrieval. In situ grouting involves the high-pressure injection of various cementitious, mineralogical, or polymeric stabilization agents into the void space within the buried waste and contaminated soil matrix to form a monolith. Upon solidification, the resultant monolith encapsulates all of the buried waste material within a dense matrix or "soilcrete," isolating it from surface and groundwater infiltration, the primary mechanism of leaching. Furthermore, the treated monolith physically stabilizes the buried waste matrix, eliminating the potential for waste subsidence that could compromise the integrity of a cap placed over the waste site. If site excavation is required, stabilization agents may be applied to produce an easily retrieved, coherent matrix, substantially controlling dust and contaminant spread. This process was adapted for use in the in situ remediation of buried hazardous and radioactive debris sites by INEEL researchers in the early 1990s (9, 10, 11, 12). This research involved cooperative efforts with private industry; AGEC-Hanford, Washington; MSE-Technology Applications, Inc.-Butte, Montana; Carter Technologies-Houston, Texas; and Geo-Con, Inc.-Monroeville, Pennsylvania; and analytical support from Brookhaven National Laboratory.

The in situ grouting (ISG) process, as illustrated in Figure 2, applies stabilization material with a drilling rig supported by a high-pressure positive displacement pump, a low-pressure feed pump and hopper assembly, associated transfer hoses, and a specialized drill string and down hole assembly. The technology involves driving a drill string into the soil /waste matrix using rotopercussion. Most insertions into buried waste seams are accomplished within 1–2 minutes of drilling time. Penetrations pierce most forms of debris and/or sealed containers. While drilling, a slow trickle flow of grout is injected at the bit end of the nozzle to reduce friction. Once inserted, grout is injected at 400 bars through the rotating drill string while withdrawing it in precise increments. The fluid flow produces a zone of intense mixing that results in complete filling of available void space. Through repeated applications on a nominally 50-cm triangular pitch matrix, a series of interconnected columns are formed, thereby forming a solid monolith out of the soil/waste seam.

A series of bench-scale material studies and associated field-scale implementation tests were performed between 1994 and 1996 at the INEEL. This work assessed the ability of various single- and two-phase grouting agents to provide contaminant compatibility and monolith development in both soils and debris. The tests were typically conducted using Subsurface Disposal Area soil, simulated waste matrices, and contaminant surrogates, to evaluate the technology's applicability for long-term waste disposal and/or waste confinement in support of retrieval. In general, examination and testing of cores and archeological excavations of full-scale monoliths yielded data that showed the jet grouting process is capable of producing dense homogenous monoliths free of voids and capable of agglomerating fine contaminants during retrieval.

Operationally, the technology matured to the point where implementation could be performed quickly and economically without spread of contaminants to the worker or the surrounding environment. In 1997, the technology was deployed at the INEEL's Subsurface Disposal Area Acid Pit site (12). A mixed waste site consisting of soils contaminated with radioactive inorganic and organic liquids from 1960s disposal actions, the Subsurface Disposal Area Acid Pit was chosen because of its thorough characterization from efforts conducted in 1991. Characterization identified mercury as the primary contaminant of concern with maximum concentrations of 5,320 ppm. Radioactive materials included Cesium-137 at 125 pCi/g and transuranic elements at only a few pCi/g levels. Approximately 3,300 gallons of grout were successfully applied to a 14 x 14 x 7 ft region of the Acid Pit over a 4- day period. Using regional and personnel monitoring, no contaminant releases were detected in the work area during or after operations. Inorganic baseline data revealed mercury in concentrations above regulatory action levels. However, all samples evaluated with TCLP protocol decisively passed, indicating successful treatment.

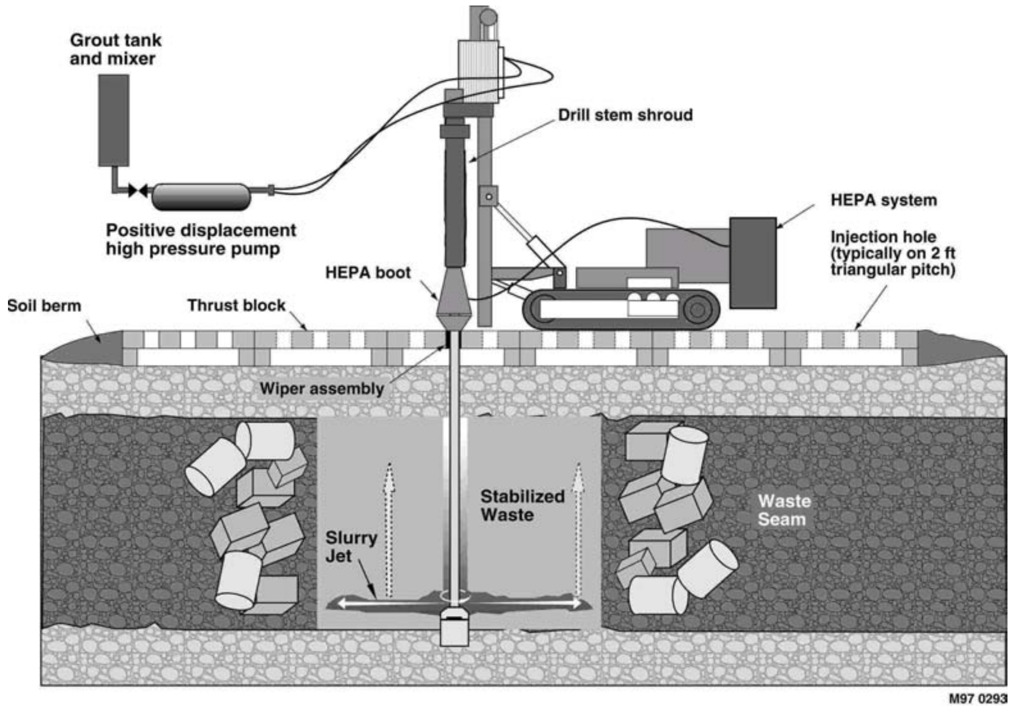

Figure 2. In Situ Grouting

ISG is a promising long-term in situ remediation alternative for the transuranic and low-level waste buried at the Subsurface Disposal Area. The primary advantage of ISG applied to the buried waste is the potentially substantial reduction in both risk and cost associated with treatment. Additionally, ISG should control the migration of contaminants to the groundwater, thus precluding the mobilization of primary contaminants of concern present in the buried waste site by producing a final waste form that encapsulates all nonvolatile contaminants and debris in its durable crystalline matrix. Final waste forms are also effective at maintaining cap stability over the waste site.

Treatability Study Objectives and Strategy

The overall objective of the ISG treatability studies is to provide sufficient data to evaluate the implementability, effectiveness, and cost of ISG applications as a viable treatment for Subsurface Disposal Area buried wastes. As discussed previously, extensive testing of the ISG applications has been performed, including a “hot” test for contaminated soil in the Subsurface Disposal Area. This technology has been developed to a point where application to a Subsurface Disposal Area buried waste site is appropriate. The focus of this treatability study is to collect information about uncertainties associated with Subsurface Disposal Area application, specifically application in a hazardous and radioactive environment with containerized waste, soil, and debris.

In applying ISG to buried transuranic waste sites for long-term disposal and/or confinement for retrieval aplications, two categories of issues need to be evaluated; implementation and effectiveness issues. The treatability studies are structured to focus on critical data gaps associate with each of these issues. The data gaps will be resolved though a combination of laboratory materials studies and a full-scale ISG test on a simulated INEEL buried waste pit. Based on this strategy, a series of white papers were prepared, evaluating the existing ISG database to address certain data gaps, and to determine those “data gaps” that need to be evaluated as part of the CERCLA treatability studies. This assessment was then used to define the test objectives. A summary of test objectives and an associated testing strategy is presented in Table 2.

Table 2. ISG Test Objectives and Testing Strategy.

ISG Treatability Study Test Objective	Strategy			
	Simulated Waste	**Actual Waste**	**Bench-scale**	**Field-Scale**
ISG (General)				
Evaluate INEEL administrative implementation for ISG*	X			X
Identify proper grouting agent/mixture for effective treatment of site.	X		X	
Evaluate worker and environmental safety during emplacement	X			X
Determine migratory potential of volatile organic compounds during ISG processing	X			X
Evaluate monitoring and verification techniques for ISG process	X			X
Generate reliable production cost data*	X			X
ISG (specific to long term disposal applications)				
Define to what extent water infiltration can be controlled over time	X		X	X
Define leachability and transportability of Subsurface Disposal Area contaminants of potential concern from the resultant waste form	X		X	X
ISG (specific to confinement during retrieval applications)				
Evaluate ease of retrieval using standard excavation equipment	X			X
Quantify reduction in contaminant air-born mobility during retrieval relative to primary containment requirements	X			X
Define leachability and transportability of Subsurface Disposal Area contaminants of potential concern from the resultant waste form as an interim action	X		X	X

* Estimate to be supplemented with data from ISV implementation and past ISG deployments

The strategy for performing the treatability studies for ISG consists of a five-phased approach:

- Phase 1, work scope planning
- Phase 2, test documentation for bench-scale and large field-scale ISG testing
- Phase 3, implementation of bench-scale mixing studies on simulated Subsurface Disposal Area waste forms
- Phase 4, implementation of a large field-scale ISG test on simulated Subsurface Disposal Area waste forms
- Phase 5, evaluation of data.

Phase 1 —Work Scope Planning. Phase 1 will evaluate all data gaps associated with ISG processing at Subsurface Disposal Area. Potential grout formulations for long term disposal applications will be investigated for their effectiveness on increasing the physical stability of the waste site, decreasing water infiltration by changing site hydraulic properties, decreasing contaminant solubility by buffering the site chemistry (oxidation reduction potential & pH), and minimizing long-term degradation. Grout formulations will also be optimized for contaminant compatibility and retrieval properties for the confinement during retrieval application. Additionally, the effects on grouting parameters from variations in the grout's physical properties will be studied. Effects on criticality potential from ISG applications will be documented and technologies and associated test designs for emplacement verification and proposed long-term monitoring will be evaluated.

Phase 2—Test Documentation. Documentation will be developed to address bench and field-scale ISG operating requirements. A treatability study work plan will be prepared to define the specific data quality objectives and experimental test designs necessary to address the data uncertainties as defined in Phase 1. A literature search and evaluation of past studies will also be conducted to predict performance and identify additional data gaps. Detailed test plans and sampling and analysis plans will be prepared for all testing activities and sample management strategies associated with each of the grouting applications. A single health and safety and waste management plan will be developed following detailed test plan development.

Phase 3—Bench-Scale Simulated Waste Tests. Following development of the documentation, bench-scale materials studies will proceed on various simulated Subsurface Disposal Area waste matrices. The primary objective of the mixing studies is to select appropriate grout formulations for each of the field studies to provide effective entrapment during retrieval and long-term immobilization of actinide elements. Resultant data will also, in part, support risk modeling of long-term stabilization in the Subsurface Disposal Area geochemical environment.

Phase 4— Field-Scale Test. A nonradioactive, nonhazardous buried waste test pit that effectively simulates anticipated conditions within the Subsurface Disposal Area will be constructed. A single pit will be constructed for both grout applications. Waste packages placed in the test pit will be of the same materials that are buried in the Subsurface Disposal Area, including 55-gal drums, cardboard boxes, metal, and plastic bags of trash. To the extent feasible, surrogates for the contaminants of potential concern will be added to the pit to assist in the technology evaluation. The test pit will be of sufficient size to fully evaluate full-scale operations.

Following preparation of the simulated waste pit, in situ stabilization will commence. Grout applications for the two grout applications will be conducted in sequence in different segments of the pit. Real-time operational data will be collected to aid in the evaluation of monolith formation (i.e., grout volume per hole, drilling and injection parameters, depth to basalt, grouted hole pattern, volume of grout returns). Both pit segments will be instrumented and monitored in real time (geophysical, soil gas/moisture, and temperature data).

Following grout emplacement and curing, the portion of the pit used to test the confinement during retrieval application will be exhumed utilizing industry standard excavation hardware. This process will be closely monitored with high volume air sampling, personnel monitors, collection and analysis of grab/swipe samples, and visual observations. Following this activity, the pit will be archeologically excavated to assess monolith formation, the extent of mixing/treatment, structural integrity, and to allow for the collection of samples for chemical and physical analysis. The analytical suite will be designed to provide data for the evaluation of grout effectiveness on the immobilization of Subsurface Disposal Area contaminants of potential concern, buffering and/or destruction of contaminants, and to simulate long-term environmental effects on the monolith material. Resultant data will support risk modeling of long-term stabilization in the Subsurface Disposal Area geochemical environment.

Phase 5—Evaluation of Data. Observations and analytical data generated by the treatability studies, in conjunction with the existing technology database, will provide adequate information to support the feasibility study process and subsequent Record of Decision for the Subsurface Disposal Area. By addressing the previously identified technical data gaps, direct assessments and subsequent risk modeling will be performed to evaluate the effectiveness of ISG for long-term disposal and confinement for retrieval applications in the Subsurface Disposal Area.

IN SITU THERMAL DESORPTION

Technology Description

In situ thermal desorption (ISTD) is the heating of contaminated soil and waste underground, raising the temperature of the soil and waste to vaporize and destroy most organics. An aboveground vapor vacuum collection and treatment system then destroys or absorbs the remaining organics and vents carbon dioxide and water to the atmosphere. TerraTherm, located in Houston, Texas, and a wholly owned subsidiary of Shell Oil Co., is the patent holder for ISTD.

The ISTD process uses electrical resistance heating elements (Iben et al. 1996), as shown in Figure 3. Heat is applied through a surface thermal blanket for applications up to 3 ft deep and through rods in wells (thermal well systems) for deeper applications (13). The treatment temperatures of the soil and waste range up to 600 to 1,000°F, depending on the target organics. The temperature is controlled by the voltage applied to the heating elements and the length of time the soil and waste is heated. The temperature is very uniform at 212°F for up to a month, depending on the power input and the soil moisture content, until all moisture in the treatment zone evaporates. Temperatures at about 300°F +20°F vaporize many organic compounds. At higher temperatures, variable amounts of organic pyrolysis and other reactions occur. Achieving 800°F temperatures may take 3 months or longer.

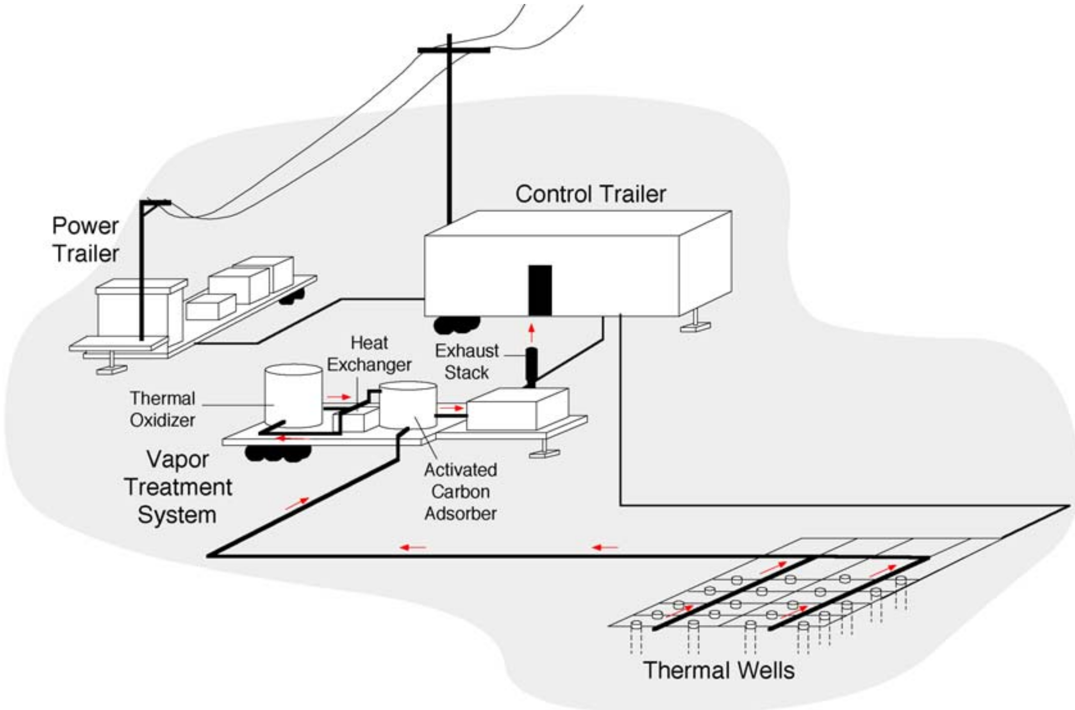

Figure 3. In Situ Thermal Desorption.

Organics that are not destroyed in the soil are extracted under vacuum and oxidized in a thermal oxidation unit. Vapors then migrate from the unit to a granular-activated carbon absorber (14). The thermal oxidation unit is the key component of TerraTherm's mobile processing unit and consists of a particulate cyclone separator and flameless thermal oxidizer operating at 900°C. Much of the destruction of PCBs in past applications has taken place underground as the vapor ascends through the heated wells (14). The performance of ISTD under high loadings of a variety of organics, including an acidic off-gas, has not been determined. The technology was originally designed for spilled fuel oil and tars that leaked into soils from refineries. The ISTD technology provides economical remediation of PCBs and lower-boiling-point organics such as aromatics and trichloroethylene (TCE).

The primary waste contaminants remediated thus far have been PCBs in soil. The first commercial demonstration of TerraTherm's ISTD process used a surface thermal blanket system. Surface soil containing PCBs at South Glens Falls Drag Strip Superfund Site in eastern New York was treated. A 4,800 ft^2 area, 1.5 ft deep, with PCB concentrations ranging up to 5,212 ppm, was remediated to less than 2 ppm with 99.99999% of the PCBs destroyed (15). The first field demonstration of the TerraTherm thermal well system remediated PCBs at the Cape Girardeau Missouri Electric Works Superfund Site in southeast Missouri (Hanke 1997). A 200-ft^2 area, 12 ft deep, with PCB concentrations ranging up to 20,000 ppm, was remediated to less than 33 ppb with 99.9999998% of the PCBs destroyed (13).

The ISTD technology has features that make it a viable alternative for remediation of volatile organics remaining in the Subsurface Disposal Area waste zones (i.e. containerized), particularly carbon tetrachloride. Vapor vacuum extraction is presently being applied to the Subsurface Disposal Area vadose zone to remediate the existing volatile organic plume. The ISTD technology potentially can remove all organics in the waste zone to nondetectable levels and likely be robust enough for operation in metals, debris, and containerized waste as well as soil. Organics in the waste and soil that would be destroyed include polyethylene, polyvinyl chloride, latex, paper, ion exchange resins, solvents, machine oil, asphalt, and heavy oils. A number of non-organics also would be destroyed by the ISTD temperatures, particularly nitrate salts. In addition, the higher ISTD process operating temperatures has the potential to chemically stabilize plutonium and other radionuclides and metals and reduce their mobility.

The heating well spacing for ISTD is a function of the remediation time desired and the number of vacuum wells and off-gas modules. The optimal desorption temperature for ISTD must be determined for the variety of contaminants and matrices in the Subsurface Disposal Area that would be affected by the anticipated temperatures.

Treatability Study Objectives and Strategy

The overall objective of the ISTD treatability study is to provide sufficient data to evaluate the implementability, effectiveness, and cost of ISTD technology as treatment for volatile organic contaminants buried in the Subsurface Disposal Area. As discussed previously, ISTD has been used for in situ soil processing at hazardous organic-contaminated sites. The focus of the treatability study is to collect information about uncertainties associated with Subsurface Disposal Area application, specifically application in a hazardous and radioactive COPC environment with containerized waste, soil, and debris. Table 3 shows the test objectives and the strategy to obtain data to satisfy the objectives.

The treatability study will be structured to focus on critical data gaps specific to the Subsurface Disposal Area application. Five phases for the treatability study have been defined:

- Phase 1, preliminary evaluation of key uncertainties
- Phase 2, test documentation of large-scale ISTD testing
- Phase 3, implementation of a large-scale ISTD test on simulated waste forms
- Phase 4, implementation of a large-scale ISTD test at the Subsurface Disposal Area
- Phase 5, evaluation of applicable data generated by the ISV treatability study.

Table 3. ISTD Test Objectives and Testing Strategy

Data Gap/Test Objective	**Strategy**			
	Simulated Waste	**Actual Waste**	**Bench-scale**	**Field-scale**
Evaluate INEEL administrative feasibility for well emplacement and ISTD process implementation	X	X		X
Determine the degree of hazardous organic contaminants and nitrate destruction in the soil, waste, containers, and off-gas treatment system	X	X	X	X
Evaluate the extent of actinide particulate contaminant release during heater and vacuum well emplacement, thermal desorption, and demobilization	X	X		X
Determine the leachability and degree of actinide fixation on treated soil	X	X	X	X
Evaluate subsidence and site stability during thermal desorption and following operations	X	X		X
Evaluate the moisture return to the treated waste site	X			X
Determine time, equipment, labor and general feasibility for mobilization, full-scale processing operations, maintenance, and demobilization	X	X		X
Evaluate ability to process gas cylinders	X			X
Evaluate the volume, type, and disposition of secondary waste	X	X		X

Phase 1—Preliminary Evaluation of Uncertainties. Phase 1 comprises an evaluation of contaminant fate and transport issues associated with ISTD processing uncertainties at the Subsurface Disposal Area. The issues must be sufficiently evaluated to define additional data needs. A substantial amount of information exists on how ISTD affects some of the hazardous contaminants in buried waste at the Subsurface Disposal Area (13, 14, 15). However, this information must be evaluated in sufficient detail to understand the probable fate of radionuclides and other contaminants.

Phase 2—Test Documentation. Documentation to adequately address full-scale ISTD operating requirements will be developed. A treatability study work plan will be prepared to define the specific data quality objectives and experimental test design necessary to address the data uncertainties as defined in Phase 1. A detailed test plan and sampling and analysis plan will be prepared for all testing activities and sample management strategies will be documented.

Phase 3—Large-Scale Simulated Waste Test. Following development of the documentation for the large-scale simulated waste test, testing will proceed on simulated waste. The primary objective of the large-scale test on simulated waste is to determine the effectiveness of the ISTD technology for treating containerized waste and debris and to evaluate the potential off-gas treatment issues.

The initial activity associated with this phase is to prepare a nonradioactive, nonhazardous buried waste test pit that effectively simulates anticipated conditions within the Subsurface Disposal Area. The waste packages that will be placed in the test pit will be of the same types of materials that are buried in the Subsurface Disposal Area, including 55-gal drums, cardboard boxes, and plastic bags of trash. To the extent feasible, surrogates of the contaminants of potential concern will be added to the pit to assist in the technology evaluation. The test pit will be of sufficient size to fully evaluate full-scale operations.

As part of the test pit preparation, temperature and pressure transducer instruments will be installed in various 55-gal drums and other sealed containers that contain vaporizable material. The instruments will provide the data necessary to determine whether all drums are breached and at what temperatures during ISTD processing.

Following the preparation of the simulated waste pit, ISTD will be performed. Various spacings for the thermal rods and vacuum wells will be used to investigate operational effectiveness. The pit will be monitored in real time, and after the test, the pit will be destructively examined to assess the effectiveness of the thermal desorption to destroy container integrity. Off-gas also will be monitored to determine the effectiveness of ISTD. Samples will be taken to analyze the effects of ISTD on the contaminants of potential concern surrogates.

Phase 4—Large-Scale Subsurface Disposal Area Test. A specific test site in the Subsurface Disposal Area will be identified. Thermal and vacuum wells will be installed in the waste zone and ISTD processing conducted.

Information on the volume of secondary waste material (e.g., condensates and HEPA filters) created from the ISTD process also will be collected. In addition, samples of each secondary waste material will be collected and analyzed to define ultimate disposition. Samples will be taken in the treated zone. Analyses from these tests will be used to provide information on the effectiveness for destruction of organics and the solubility of the remaining radionuclide contaminants of potential concern.

Phase 5—Evaluation of Data from the ISTD Treatability Study. The data from the large-scale cold and hot tests will be analyzed and summarized in a final report summarizing ISTD application to buried waste sites within the Subsurface Disposal Area. The final report will provide sufficient ISTD performance and operational data to support the comprehensive feasibility study for Subsurface Disposal Area.

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